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Optimization of web-core steel sandwich decks at concept design stage using envelope surface for stress assessment

J. Romanoff *

Department of Applied Mechanics/Marine Technology, Aalto University, P.O. Box 15300, 00076 Aalto, Finland

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ABSTRACT

This paper presents an optimization method for laser-welded web-core steel sandwich panels supported by girder system. The method utilizes homogenized plate theory and offset beams. The static and eigenfrequency analyses are carried out using the Finite Element Method (FEM). In order to assess the influence of periodic stresses within the sandwich panel, an envelope surface approach is developed. The approach is aimed to capture the maximum stresses on elemental basis even though the actual positioning of the web plates is unknown. This makes the method attractive for concept design stage where nesting process is not yet done. The envelope surface approach is validated with 3D FEM and periodic solution based on localization. The agreement between methods is found to be excellent. The method is demonstrated through a case study on weight optimization of passenger ship deck. The optimization problem is solved using Particle Swarm Optimization method. The paper shows that the proposed approach can be efficiently used to assess the stresses of the sandwich panel and thus to design steel sandwich structures at concept design stage.

1. Introduction

Demand for lighter, safer and modular plate structures has stimulated the need to study new structural configurations for example in marine and civil engineering. Steel sandwich panels, with prismatic cores, offer an option to fulfill these requirements; see. Fig. 1. The low density core can be constructed from different types of profiles, e.g. corrugations [1–9], C- [10], [11] and Z- [12,13] profiles, etc. Web-core sandwich panels [14–24], with flat plates as the core are interesting alternative. These panels have high stiffness to weight, stiffness to strength ratio. In addition, the unidirectional, hollow core can be used to integrate functions, such as cabling. The potential of these new structural concepts can be exploited fully only when they are optimized for given application case; see Refs. [25–34]. The structural optimization requires assessment of the structural performance and algorithm to minimize the weight, cost, etc. Structural assessment of web-core panels during optimization is challenge due to differences of scales between the deck, the unit cell of the sandwich, and the laser-stake weld connecting the face and web plates; see Fig. 1. Typically the number of unit cells on a deck plate between the supports such as girders is in the range of 10–100. However, often the girder spacing is not multiple of the unit cell size. This sets challenges to structural modeling using 3D Finite Element Method as the periodic mesh need account with good accuracy the unit cell response making the mesh relatively dense and computationally expensive. On the other hand, at plate edges, the unit cell size can be different to that elsewhere in the plate. This affects the stress response.

Furthermore, as presented in Refs. [20,21] the prediction of maximum deflection requires modeling of the laser-weld rotation stiffness, since it affects the transverse shear stiffness of the panels, see Refs. [23]. Due to same effect, also the bifurcation buckling stress is reduced [24]. Local buckling of the face and web plates requires either 3D FE-modeling of the panel topology [27], or closed-form buckling formulae [29]. Face and core yielding have been shown to be active constraint in numerous investigations and typically these require consideration of the unit cell response, i.e. 3D FE-modeling [8,20,21,25,26]. Alternative to 3D FE-modeling is to use of homogenized plate theory; see Fig. 2. It is shown in Refs. [4,10–13,18–21,23] that the deflection distributions of various type sandwich panels can be described accurately using homogenized plate theory. Refs. [30–32] present that the free and forced vibration of truss-core sandwich panels can be accurately estimated using homogenized plate theory. Refs. [20,21] present that the normal and shear stresses in the face and web plates can be accurately predicted using homogenization-localization framework for beams containing as few as 10 unit cells along the length

* Tel.: +358 50 511 3250.
E-mail address: jani.romanoff@aalto.fi

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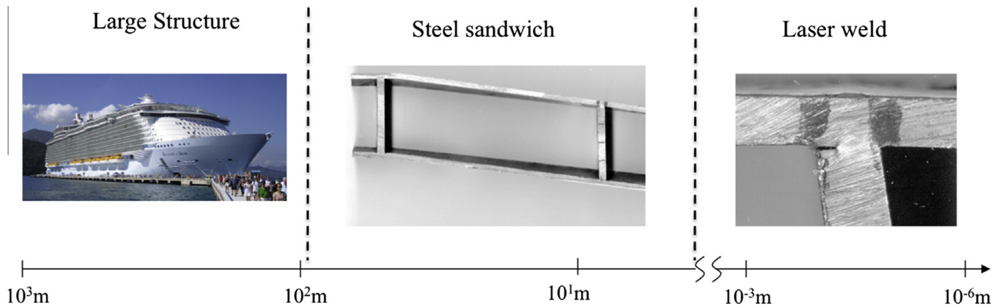

Fig. 1. The difference of scales between ship structure, unit cell of the web-core sandwich panel in deck or bulkhead and laser-stake weld.

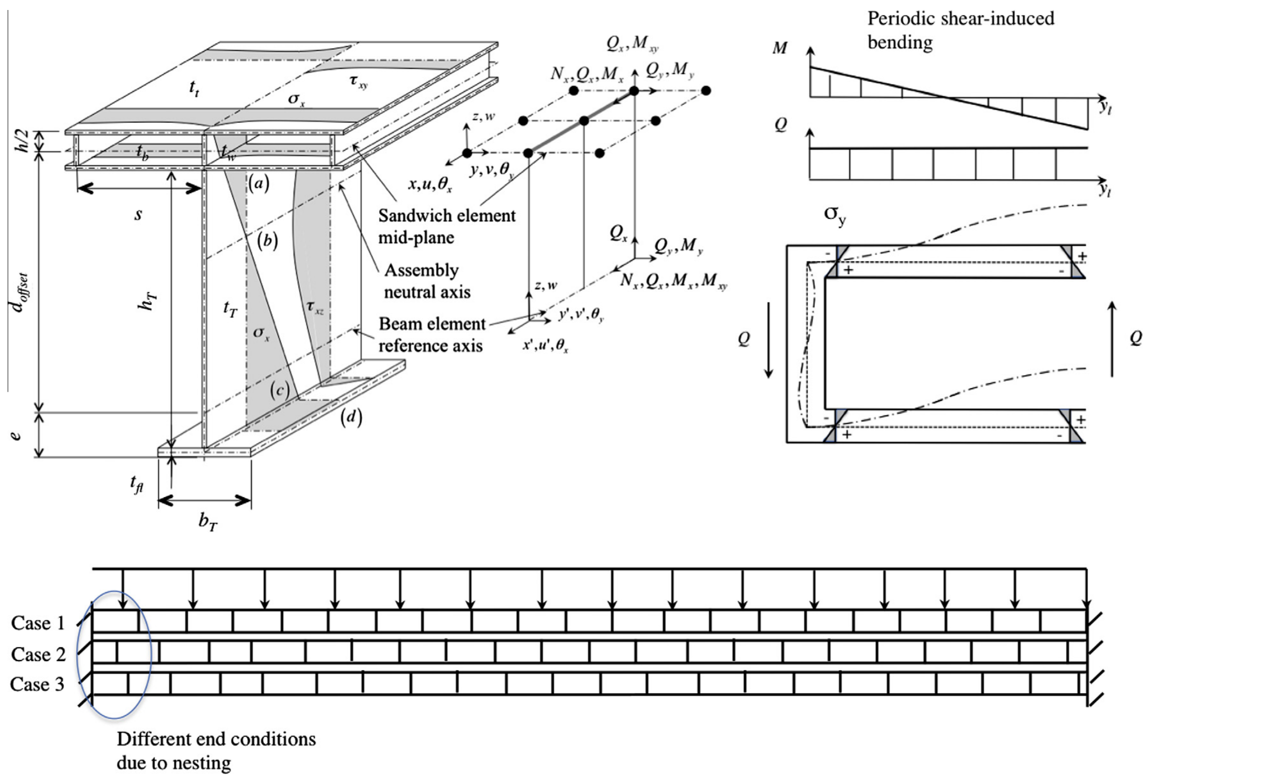

Fig. 2. Modeling the periodic structure with equivalent single layer shell and offset beam element accounting the periodic shear-induced bending moments and various end conditions for periodic structure.

of the beam. In Ref. [35] it is shown that the interaction between supporting girder system and the sandwich panel can be predicted accurately in terms of stresses and deflections using the same concepts. Thus, in concept design stage where the adequacy of the structure needs to be checked against the design rules and criteria, the approach coupled with closed from expressions for buckling [9,25,29,33] and yielding [9,25,33] gives a powerful design tool. This is due to the fact that the approach leads to considerable computational savings as the required mesh is created only once, it is smaller than full 3D FE-model and during the optimization only the stiffness parameters of the mesh are varied. However, the localization method requires knowledge of the positions of the web plates with respect to the plate boundaries; see Fig. 2. In addition, it requires interpolation and integration of the Finite Element results over entire plate domain instead of working within the element. Thus, in concept design stage where nesting is not yet done, this approach is infeasible.

The purpose of this paper is to present optimization methodology for web-core sandwich decks in concept design that utilizes the envelope surface to account the maximum shear-induced normal stresses when the actual positioning of the web plates is not known. The idea is not to capture the actual periodic stress distribution but rather, envelope surface that represents the maximum values of the stresses. The approach is validated using 3D Finite Element Models of the actual 3D topology. The speed of the method is demonstrated through case study on accommodation deck in which the strength criteria are buckling, yielding, maximum deflection, space requirement and lowest eigenfrequency. The optimization is carried out using Particle Swarm algorithm from Ref. [39].

2. Definitions

The web-core sandwich plate consists of web and face plates, which are connected by laser welds; see Fig. 1. The web plates are parallel to the *xz*-plane and have the thickness t_w and the height h_c; see Fig. 2. The web plate spacing is *s*. The top and bottom face plates are parallel to the *xy*-plane and have the thicknesses t_t and t_b respectively. The sandwich plate has the length *L*, the